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COOLING CAPACITY OF CONTEMPORARY HARDENING DIFFUSERS

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The design and technological parameters of diffusers for hardening sheet glass on contemporary production lines are considered. The limiting lower level of the thickness of glass that can undergo air-jet hardening is determined.

Recently the range of hardened-glass products has been undergoing significant qualitative changes, the main one of which is a decrease in thickness from 5 – 6 to 3.2 mm.

In this context, the need for fundamental changes in the technological aspects of hardening has been discussed regarding intensification of cooling in hardening [1 – 3].

The purpose of the present paper is to summarize information on diffuser designs and operating conditions and to determine the lower limit of the thickness of glass that can undergo air-jet hardening.

An analysis of contemporary designs of hardening diffusers corroborated the previous conjecture and its experimental substantiation indicating that the most efficient design is a cylindrical nozzle with a conoid air input [1]. The cooling capacity in all other nozzle designs (a simple opening in the wall, conoid, cylindrical, etc.) is 10 – 40% less, the comparison parameter being the coefficient of heat transfer α from the cooled surface to the coolant.

The only aspect that to some extent hampered the analytical study of the cooling-unit efficiency was the fact that the nozzle geometry in a lateral cross section deviated from purely cylindrical. Thus, SIV (Italy), Tamglass (Finland), and other production lines tend to use nozzles deformed in the direction perpendicular to the glass motion along the roller conveyer. Their flow cross section is either oval or an elongated hexagon, with the purpose of covering a greater cooling area over the width of the article. In this way the inhomogeneity of the "chain"-stress distribution in this direction is reduced, and a decrease in the inhomogeneity of hardening along the length of the article is accomplished by meanns of relatively high transport velocities (up to 10 m/sec).

The method for calculating the cooling capacity of this type of diffuser is corrected by introducing the equivalent diameter of the nozzle:

$$D_e = 2\sqrt{A/\pi}\,,$$

where A is the surface area of the flow cross section of the actual nozzle.

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Thus, the diffuser calculation algorithm is reduced to the following.

The parameters given are D_e, the nozzle spacing X, the distance from the nozzle exit to the cooled surface Z, and the physical constants of air (thermal conductivity k, dynamic viscosity μ, and density ρ).

The parameters to be calculated are:

– the air velocity at the nozzle exit

$$\omega_e = \varphi\sqrt{2p/\rho}\,,$$

where φ is the outflow coefficient; p is the excess air pressure in the diffuser;

– the so-called "impact" air velocity, where if

$$\frac{Z}{D_e} \geq 8,$$

then

$$\omega_a = 6.63\frac{D_e}{Z}\omega_e\,,$$

and if

$$\frac{Z}{D_e} < 8,$$

then

$$\omega_a = \omega_e\left(1 - 0.416\times10^{-4}\frac{Z^4}{D_e^4}\right);$$

– the Reynolds number

$$\mathrm{Re} = \omega_a\frac{X\rho}{\mu}\,;$$

– the sought quantity

$$\alpha = 0.286\frac{k}{X}\mathrm{Re}^{0.625}.$$

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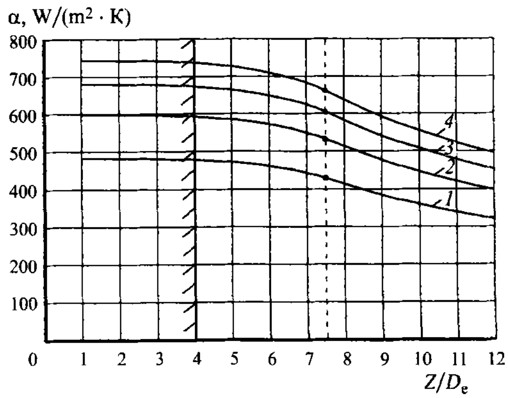

Fig. 1. Cooling capacity of a diffuser versus the parameter Z/D_e: *1*, *2*, *3*, and *4*) p = 10, 20, 30, and 40 kPa.

The algorithm presented here was tested repeatedly, and the calculation results have good convergence with experimental data [1, 3].

In order to obtain specific numerical values of the heat transfer coefficient α, a computer experiment was performed with fixation of the parameters D_e = 10 mm and X = 45 mm (these values correspond to actual parameters of diffusers currently used).

Figure 1 selectively shows dependences on the dimensionless parameter Z/D_e for a pressure in the diffuser varying from 10 to 40 kPa. It was established earlier [4] that operation of diffusers at $Z/D_e \leq 4$ is economically inefficient. We shall regard this as a nonworking region and distinguish it by shading in Fig. 1. Moreover, by limiting oneself to the optimum value Z/D_e = 7.5 [4], we obtain several values of α that can be provided by the given diffuser, which are shown in Table 1.

The third column in Table 1 was filled in based on a calculation of the limiting thickness of glass d_{lim} for which full

TABLE 1

p, kPa	α, W/(m^2 · K)	d_{lim}, mm
10	430	3.95
20	520	3.28
30	605	2.82
40	660	2.58

hardening is still possible according to the study in [3], which gives

$$d_{lim}\,\alpha = 1708 \text{ mm} \cdot \text{W/(m}^2 \cdot \text{K)}.$$

A pressure of p = 40 kPa appears to be the limiting pressure for industrial plants. Indications of damage ("crumpledness") are observed at this level, and the level of sonic pressure exceeds the permissible values. Therefore, without fundamentally changing the diffuser design, the minimum thickness of sheet-glass articles with adequate hardening can be 2.6 – 2.8 mm.

The design and technological possibilities of the considered type of hardening diffuser at the current level can be considered exhausted.

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